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PATENT APPLICATION

TEMPERATURE ACTUATED POSITIONING DEVICE FOR NON-LINEAR OPTICAL ELEMENTS

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BACKGROUND OF THE INVENTION

The present invention is generally related to devices and methods for controlling and converting laser energy wavelengths, and in a particular embodiment, provides a passive temperature compensation system for a nonlinear optic.

Lasers have been used for several years to sculpt materials into very precise shapes. excimer lasers are now widely used to ablate tissue in a variety of surgical procedures, particularly for corneal ablation during refractive surgery. The exposure of the tissue is typically controlled to produce a desired change in corneal shape. The change in corneal shape may be intended to correct a refractive error of the eye so as to eliminate the need for corrective eye glasses, or may be intended to remove a pathology from the eye.

Known laser eye procedures generally employ ultraviolet or infrared lasers to remove a microscopic layer of stromal tissue from the cornea to alter its refractive characteristics. The laser often has a frequency selected to result in photodecomposition of the corneal tissue, preferably without causing significant thermal damage to adjacent and underlying tissues of the eye. These selected frequencies can break the radiated molecules into smaller volatile fragments photochemically by directly breaking the intermolecular bonds. These known refractive lasers often deliver laser energy as a series of discrete energy pulses, with each pulse having sufficient energy to ablate a thin volume from adjacent the corneal surface. The refractive surgical system generally control the distribution of the ablative laser energy across the cornea using, for example, ablatable masks, movable apertures, scanning systems that move the laser across the corneal surface, combinations of these techniques, and the like.

An exemplary system and method for sculpting a cornea by controlling a plurality of laser beams is described in co-pending U.S. Patent Application No. 09/274,499 as filed on April 23, 1999, the full disclosure of which is incorporated herein by reference.

While known laser eye surgery systems have been found to be highly effective, as with all successes, still further improvements would be desirable. In

particular, known laser eye surgery systems often rely on excimer lasers to produce laser energy in the deep ultraviolet wavelengths. To produce this laser energy, these excimer lasers often make use of gases such as argon-fluoride to produce a beam having a wavelength of about 193 nm. Although such excimer lasers are highly effective, there are significant maintenance costs associated with consumption of gases in the laser. Servicing costs and the lifetime of the laser chamber are less than ideal, while cleaning and replacement of the optical components is more often than would be desired.

Solid-state lasers have a number of desirable characteristics. For example, these lasers may allow higher repetition rates than excimer lasers. Solid-state lasers may also cost less and have a longer useful life than an excimer laser. Unfortunately, solid-state lasers generally do not provide highly coherent radiations in the deep ultraviolet wavelengths, which are desirable for ophthalmic surgery and for other applications including semiconductor processing, diagnostic applications, and the like.

It has previously been proposed to make use of solid-state lasers for refractive surgery and other applications by converting the laser output wavelength to a more desirable frequency using Non-Linear Optics (sometimes referred to as NLO's). Non-Linear Optics generally produce energy which is significantly different than the radiation incident thereon. Non-Linear Optics include beta barium borate, lithium triborate, cesium lithium borate, periodic pooled lithium niobate ($LiNbO_3$), and other materials such as RTA, RTP, GaAs, KTA, KTP, $LiTaO_3$, lithium tantalate, and the like. These and other nonlinear crystals can be used to convert laser energy having an initial wavelength to an alternative laser energy having a wavelength which is a harmonic of the initial wavelength, for example, by doubling a frequency of the laser energy. These and other nonlinear crystal materials may also be used to combine two or more differing laser input energies to produce an output energy of a desired wavelength, for example, by mixing the input laser energy so as to sum frequencies for the output laser energy. An exemplary method and system for producing coherent deep ultraviolet output from a solid state laser is described in U.S. Patent No. 5,742,626 issued to *Mead et al.*, the full disclosure of which is incorporated herein by reference.

While the frequency multiplied and sum-mixed outputs of the proposed ultraviolet solid-state laser systems provide significant potential advantages for use in laser eye surgery, semiconductor fabrication, and other uses, these proposed solid-state systems have their own disadvantages. In general, the energy conversion provided by Non-Linear Optics can vary significantly with temperature. More specifically, the angle

beam directing system selectively directs the beam toward portions of a cornea so as to effect a desired change in a refractive characteristic of the cornea.

In a method aspect, the invention provides a method comprising generating a laser beam at a first frequency with a laser. The laser beam is converted to a second frequency with a NLO. The converting step varies with a temperature of the NLO, and with an angle defined by the NLO and the laser beam. Temperature-induced variations in the NLO are passively compensated for by transferring heat to a member from the NLO. Thermal expansion of the member resulting from the transfer of heat adjusts the angle of the NLO.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 schematically illustrates a laser eye surgery system and method according to the principles of the present invention.

Fig. 2 is partial cross-sectional view showing a Non-Linear Optic (NLO) for converting a frequency of a laser beam and a support system supporting the NLO so that a change in temperature of the NLO varies an angle of the NLO relative to the laser beam.

Fig. 3 schematically illustrates an exemplary solid-state laser system including a plurality of temperature actuated positioning systems for an associated plurality of non-linear optical elements.

DESCRIPTION OF THE SPECIFIC EMBODIMENTS

Referring now to Fig. 1, a refractive surgery system 10 selectively directs laser energy 12 onto a corneal surface S of eye E. As is well described in the patent literature, surface S may be a surface of a stromal tissue. This stromal tissue may be exposed by removing an overlying epithelial layer of the cornea by laser ablation, scrapping, abrasion, or the like. In many cases, the surface S of the stromal tissue will be exposed by selectively incising the cornea and displacing a portion or "flap" of the corneal tissue while the flap remains attached outside the visually used portion of the cornea, in a procedure referred to as *laser in situ keratomileusis* (LASIK).

Laser system 10 generally includes a laser 14 and a beam directing system 16, both of which are coupled to a controller 18. Controller 18 will typically comprise a processor such as a PC workstation including a program stored on a tangible medium so as to selectively direct laser energy 12 onto surface S of the cornea.

In general, the non-linear optics of exemplary laser system 10' will be coupled to positioning devices 30 as described above with reference to Fig. 2, so as to avoid and/or decrease reliance of the solid-state laser system on active control of the position and/or temperature of the non-linear optics using sensor actuated motors, thermal control systems, and the like. While such active control systems may be used in conjunction with the passive, thermally activated positioning system described herein, it may be possible to decrease and/or eliminate some or all of the active controls for the non-linear optical elements for multi-component solid-state laser systems, such as that illustrated in Fig. 3.

While the exemplary of the present invention has been described has been described in some detail by way of example, and for clarity of understanding a variety of modifications, changes, and adaptations will be obvious to those of skill in the art. Hence the scope of the present invention is limited solely by the appended claims.